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(54) Title: METHOD AND APPARATUS FOR PRODUCING DIRECTIONALLY SOLIDIFIED CASTINGS

(57) Abstract

The present invention relates to an apparatus for metal casting and can be used in producing castings with directional and single crystal structure. The apparatus comprises a vacuum chamber (12) inside which there is disposed an induction melting furnace (15), a mold preheating furnace (9) with a ceramic mold (1), and a water-cooled tank (6) being shaped as a truncated cone having a bottom portion (16) and an upper portion (17) which is opened towards a heating zone (10). The heating zone (10) and the cooling zone (13) are separated by a baffle (5) articulating in a horizontal plane and consisting of segments or sectors. The apparatus allows the production of high quality castings having the directional and single crystal structure including the large sized castings by both the method of radiation cooling and the method of liquid metal cooling. Said invention gives the possibility to use successively the disclosed apparatus as a mold catch basin in the event of mold breakage and to increase the reliability and economic profitability of the apparatus' performance.

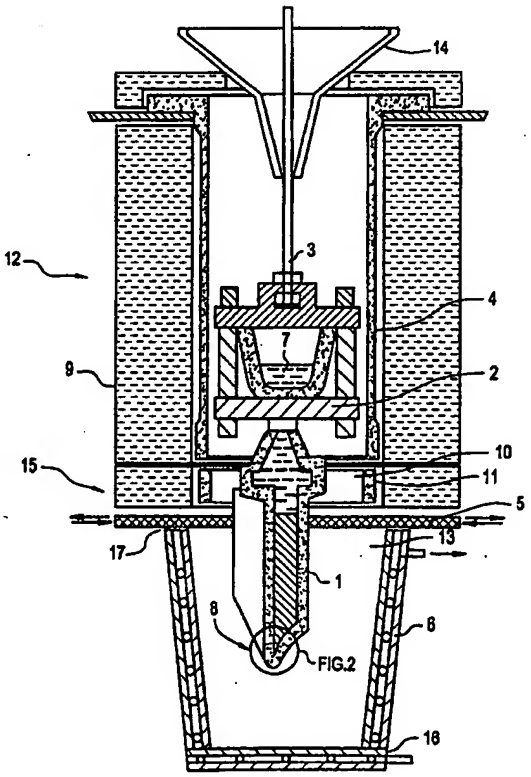

FIG.2

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METHOD AND APPARATUS FOR PRODUCING DIRECTIONALLY SOLIDIFIED CASTINGS

FIELD OF THE INVENTION

The present invention relates to metal casting and can be used in producing castings with directional and single crystal structure. In particular the invention relates to a metal casting apparatus with a water-cooled tank having a truncated cone shape.

BACKGROUND OF THE INVENTION

An apparatus for directional solidification generally comprises a vacuum chamber inside which there are disposed a mold heating zone, a baffle system, a water-cooled chill plate usually made of copper, an induction furnace, and a thermocouple system that automatically controlls and maintains the temperature in a cooling zone and in a heating zone within the furnace. Such features are disclosed in U.S. Patent Nos 3680625, 4804311, and 4412577.

Also known in the art is an apparatus for directional solidification, in which the cooling zone is a liquid cooling bath with a material that melts easily to serve the role of the cooling medium. The liquid metal bath is disclosed in U.S. Patent Nos 3763926 and 3915761, and Russian Federation Patent No 2010672.

Apparatuses in which both types of the above mentioned assemblies are combined (i.e., the copper chill plate and the liquid metal cooling bath) are also known. But those apparatuses comprise two actuators for vertical transportation of a mold with a metal casting. These actuators are disposed above and beneath the vacuum chamber housing. For that reason the dimensions of the apparatuses are enlarged and the service of the installations become complicated

while the reliability of the apparatuses is decreased (see U.S. Patent 5197531, and the publication Singer R.F. "Directional and Single Crystal Solidification Using LMC").

The closest prior art to the present invention is an apparatus disclosed in French Patent Application 2604378, being accepted as a prototype. This prototype apparatus comprises a vacuum chamber with a heating member inside where there is disposed a ceramic mold fixed on a water-cooled metallic plate which is moved up and down with the help of a rod and of an actuator for vertical transportation. A horizontal baffle separates a heating zone and a cooling zone. In the cooling zone, concentrically with the chill plate, there is disposed an additional circular water-cooled cavity with the inner diameter exceeding the mold's maximal size. Below the cavity there is disposed a container which is utilized for capturing the poured casting metal in the event of mold breakage.

The above apparatuses, including the prototype, can function only when they comprise a crystallizer. It is impossible to use such installation for directional solidification processing with a liquid metal coolant and it is difficult to utilize the expensive alloys used in directional solidification castings in the event of mold breakage. Thus there is a need for a casting apparatus that provides a means that efficiently cools the molten cast alloy while protecting the equipment from damage in the event that the ceramic mold breaks while containing the molten cast alloy material.

SUMMARY OF THE INVENTION

The technical aim of this invention is to produce castings having the directional and single crystal structure by the method of radiation cooling without using the above-mentioned crystallizer. Another aim of the invention is to be able to reconstruct easily the invented apparatus for both radiation crystallization processing and liquid metal cooling crystallization processing. The inventive apparatus

also increases the reliability and economic profit due to the apparatus' performance.

To achieve said aim the inventive apparatus comprises a vacuum chamber inside which there is disposed an induction melting furnace, a mold preheating furnace with a ceramic mold, a drive assembly for mold transportation and a water-cooled tank. The drive assembly comprises a rod on which the mold is fixed with the help of a hanger and a regulating actuator for vertical movement being positioned above the vacuum chamber. The water-cooled tank is shaped as a truncated cone. Its upper portion is opened towards the heating zone, and its bottom portion has a smaller base than the upper portion. A baffle separates the heating zone inside the induction furnace from the cooling zone; said baffle moves in a horizontal plane and closely adjoins the mold during the solidification process. It consists of the segments or sectors (not less than 2 from each side).

BRIEF DESCRIPTION OF THE DRAWING

Figs.1 and 2 show a schematic drawing of the apparatus where 1 is the ceramic mold, 2 is the hanger to fix the mold to the drive assembly, 3 is the rod, 4 is the heater of the mold preheating furnace, 5 is the heat baffle, 6 is the water cooled tank, 7 is the molten superalloy, and 8 is the starting zone with a seed.

DESCRIPTION OF THE INVENTION

The apparatus performs as follows: the mold (1) is disposed on the hanger (2) and is fixed on the movable rod (3). The hanger (2), the movable rod (3), and the regulating actuator comprise the drive assembly (14). The mold (1) is placed into the mold preheater furnace (9) with the help of the actuator while regulating the mold position relative to the heater (4). The heat baffle (5) is disposed under the heating zone (10). The top butt end of the water-cooled tank (6) adjoins the baffle's (5) lower surface and is positioned coaxially with

the heater (4) and (11). The vacuum chamber (12) is evacuated to 1 x 10^{-3} mm m.c. The mold preheating furnace (9) is switched on. Upon reaching the mold temperature of 100-150 °C higher than the liquidus temperature of the alloy being cast, the induction furnace's heater (11) is switched on, the alloy (7) being cast melts and is poured into the heated ceramic mold at the predetermined temperature. After that, the actuator for vertical transportation lowers the mold from the heating zone (10) into the cooling zone (13) at the required rate. Solidification of the molten cast alloy occurs by radiation onto the cold walls of the water-cooled tank. Due to this fact it becomes possible to produce large sized castings with directional and single crystal microstructure. Large size castings can include blades, nozzles, buckets, airfoils, and the like, that are used both in aircraft and land-based turbine engines. The castings are often greater than 30 inches in overall height.

Once the mold with the casting alloy has been lowered along its complete height into the cooling zone, the heater (4 and 11) is switched off. When the temperature is decreased to 300-400 °C, the mold with the solidified casting alloy is extracted from the installation which has been previously decompressed. Then the process is repeated for the next mold.

In another aspect of this invention, in order to produce blades having single crystal structure with desired orientation, a single crystal seed with proper orientation is positioned into the top of the starting zone (8) of the ceramic mold before it is disposed in the vacuum chamber. Then the mold position is strictly fixed relative to the heater. In such event the seed and the solidified portion of the starting zone serve as a cooling medium, and further solidification of the melt is caused by radiation cooling in the water-cooled tank as stated above. The use of the water-cooled tank instead of a chill plate allows the same or better working efficiency of said tank than that of a chill plate or of the prototype circular water-cooled cavity. At the same time the water-cooled tank of this invention does not require the use of a complex drive assembly with airtight seals.

As stated above, the heat baffle (5) is used for raising the axial temperature gradient at the solidification front. Said baffle moves in a horizontal plane, closely adjoins the ceramic mold according to its geometry during the solidification process and consists of the segments or sectors (not less than 2 from each side).

In the inventive apparatus the water-cooled tank may be made of stainless steel and contain a double layer wall surrounding the perimeter of the tank. A vacuum atmosphere is created in the tank to further aid in the cooling of the cast parts. The tank may also effectively function as a mold catch basin in the event of mold breakage, and the expensive, poured casting alloy may be easily removed from the tapered tank and be remelted.

The apparatus of this invention allows one to produce high quality castings having the directional and single crystal structure, including the large sized castings used in the land based turbine industry, by the method of radiation cooling without using the crystallizers of the prior art. The invention also gives the possibility to reconstruct easily the disclosed apparatus for liquid metal cooling crystallization processing, to use successively the invented water-cooled tank as a mold catch basin in the event of mold breakage, and to increase the reliability and economic profitability of the apparatus' performance.

What is claimed:

1. An apparatus for producing castings with directional and single crystal structure, comprising a vacuum chamber (12) inside which there is positioned an induction melting furnace (15), mold preheating furnace (9) with a ceramic mold (1), mold transportation drive assembly (14) consisting of a rod (3) and an actuator for vertical movement, and a baffle (5) separating a cooling zone (13) and a heating zone (10); said apparatus being characterized in that the cooling zone (13) means a water-cooled tank (6) having a bottom portion (16) and an upper portion (17) being opened towards the heating zone (10).

2. The apparatus of claim 1 characterized in that the water-cooled tank (6) is shaped as a truncated cone with its bottom portion (16) having a smaller base than the upper portion (17) of the tank (6).

3. The apparatus of claim 1 characterized in that a baffle (5) articulates in a horizontal plane and consists of at least two sectors or segments, closely adjoining the ceramic mold (1) during a solidification process.

4. The apparatus of claim 1 where the drive assembly (14) further comprises a mold hanger (2).

5. The apparatus of claim 1 where said water-cooled tank (6) can be used as a mold catch basin.

6. The apparatus of claim 1 where said mold (1) contains a starter cavity (8) for a crystal having a defined crystal orientation.

7. The apparatus of claim 1 where the water-cooled tank (6) has a double wall.

8. The apparatus of claim 1 where the water-cooled tank (6) is made of stainless steel.

9. A method of making a directional or single crystal alloy structure comprising the steps: placing a mold (1) in a mold preheating furnace (9) relative to a heater (4) ; heating the mold (1) to a temperature of about 100 to 150 ^{0}C above the liquidus temperature of a casting alloy; melting the casting alloy; pouring the molten alloy (7) into the heated mold (1); lowering the mold (1) with the molten alloy at a required rate from a heating zone (10) into a cooling zone (13) comprising a water-cooled tank (6); and solidifying the molten alloy by radiation onto the water-cooled walls of the tank (6).

10. The method of claim 9 where the mold (1) passes through a baffle (5) located between the heating zone (10) and the cooling zone (13).

11. The article made according to the method of claim 9.

12. The article made according to the method of claim 9 having a single crystal structure.

13. The article made according to the method of claim 9 comprising an airfoil.

14. The article according to claim 13 having a length greater than 30 inches.

FIG.1

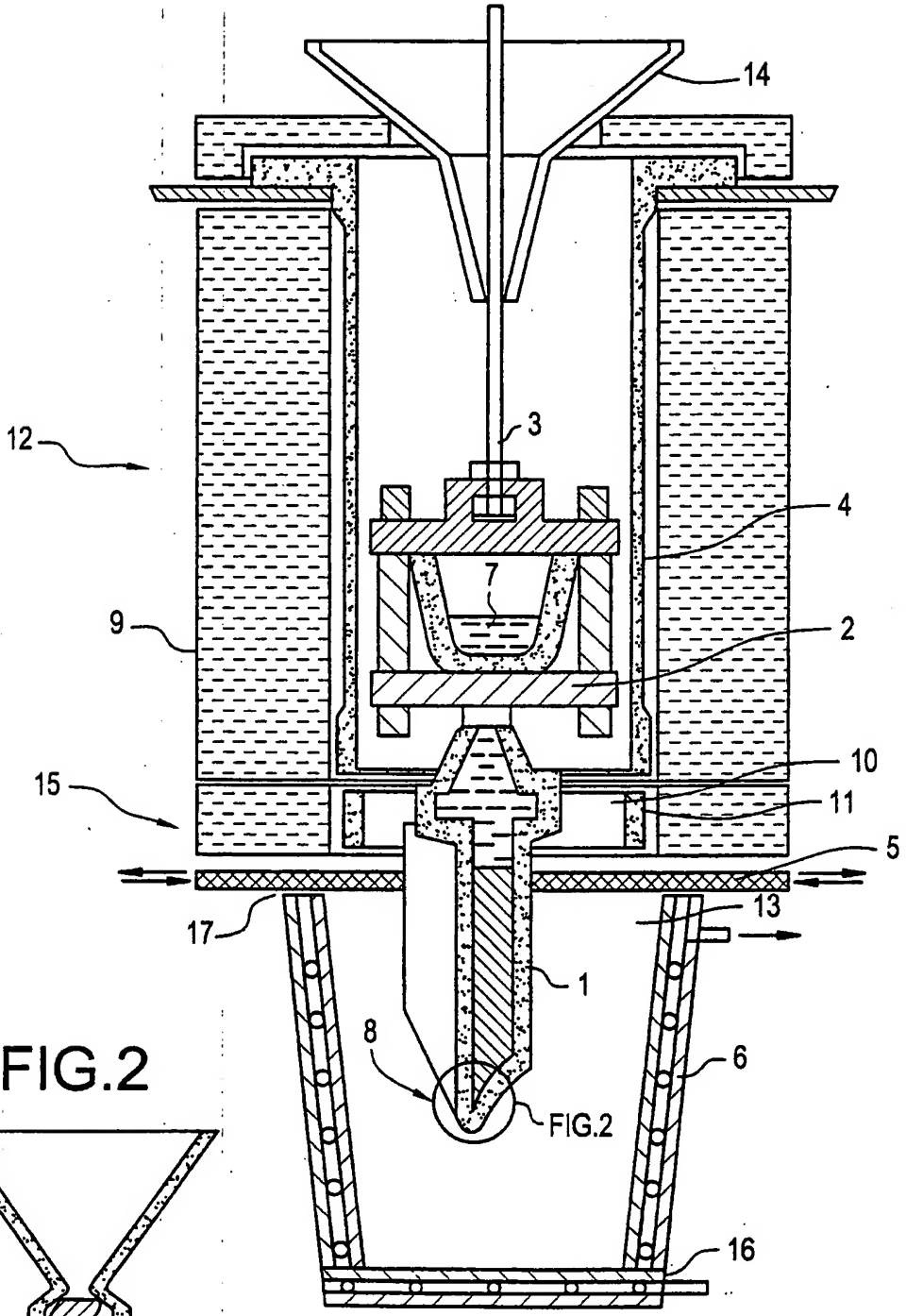

FIG.2

INTERNATIONAL SEARCH REPORT

Int ional Application No
PCT/US 98/19021

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B22D27/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B22D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 168 916 A (J.-C. DORIATH ET AL.) 8 December 1992 see claim 1; figures 1-6 & FR 2 604 378 A cited in the application	1,9
A	US 3 680 625 A (F. J. HEIN ET AL.) 1 August 1972 cited in the application see claim 1; figures 1-3	1
A	US 4 804 311 A (N. P. ANDERSON ET AL.) 14 February 1989 cited in the application see claim 1; figures 1-13	1

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Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 412 577 A (R. W. SALKELD ET AL.) 1 November 1983 cited in the application see claim 1; figures 1-8	1
A	US 3 763 926 A (J. G. TSCHINKEL ET AL.) 9 October 1973 cited in the application see claim 1; figures 1-8	1
A	US 3 915 761 A (J. G. TSCHINKEL ET AL.) 28 October 1975 cited in the application see claim 1; figures 1-8	1
A	SOVIET PATENTS ABSTRACTS Section Ch, Week 9503 Derwent Publications Ltd., London, GB; Class M22, AN 95-020454 XP002085790 & RU 2 010 672 C (AVIAT MATERIALS RES PRODN ASSOC), 15 April 1994 cited in the application see abstract	1
A	US 5 197 531 A (F. HUGO ET AL.) 30 March 1993 cited in the application see claim 1; figures 1-9	1
A	US 3 532 155 A (L. I. KANE ET AL.) 6 October 1970 see claims 1,3; figure 2	1,9
A	GB 2 309 405 A (ALD VACUUM TECHNOLOGIES GMBH) 30 July 1997 see claim 1	1,9
A	EP 0 631 832 A (LEYBOLD DURFERRIT GMBH) 4 January 1995 see claim 1; figures 1-3	1,9
A	EP 0 749 790 A (ABB RESEARCH LTD.) 27 December 1996 see claim 1; figure	1,9

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int ional Application No
PCT/US 98/19021

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 5168916 A	08-12-1992	FR	2604378 A	01-04-1988
		DE	2926194 C	09-06-1988
		GB	2195277 A,B	07-04-1988
		IN	168000 A	19-01-1991
		JP	4059990 B	24-09-1992
		JP	63290679 A	28-11-1988
		SE	460771 B	20-11-1989
		SE	8701505 A	11-10-1988
US 3680625 A	01-08-1972	FR	2113833 A	30-06-1972
		GB	1303028 A	17-01-1973
US 4804311 A	14-02-1989	NONE		
US 4412577 A	01-11-1983	AU	559152 B	26-02-1987
		AU	1782283 A	14-02-1985
		CA	1211341 A	16-09-1986
		DE	3329306 A	28-02-1985
		FR	2550556 A	15-02-1985
		GB	2144357 A,B	06-03-1985
		JP	1714372 C	27-11-1992
		JP	3079103 B	17-12-1991
		JP	60044168 A	09-03-1985
US 3763926 A	09-10-1973	AU	469051 B	29-01-1976
		AU	4675472 A	21-03-1974
		CA	964032 A	11-03-1975
		CH	566832 A	30-09-1975
		DE	2242111 A	22-03-1973
		FR	2152649 A	27-04-1973
		GB	1369270 A	02-10-1974
		JP	48038236 A	05-06-1973
		NL	7211674 A	19-03-1973
		SE	384643 B	17-05-1976
		US	3915761 A	28-10-1975
US 3915761 A	28-10-1975	AU	475256 B	19-08-1976
		AU	5465573 A	24-10-1974
		CA	981487 A	13-01-1976
		DE	2324376 A	06-12-1973
		FR	2184610 A	28-12-1973
		GB	1426805 A	03-03-1976
		JP	49049822 A	15-05-1974
		SE	388795 B	18-10-1976
		AU	469051 B	29-01-1976
		AU	4675472 A	21-03-1974
		CA	964032 A	11-03-1975
		CH	566832 A	30-09-1975
		DE	2242111 A	22-03-1973
		FR	2152649 A	27-04-1973
		GB	1369270 A	02-10-1974
		JP	48038236 A	05-06-1973
		NL	7211674 A	19-03-1973
		SE	384643 B	17-05-1976
		US	3763926 A	09-10-1973
US 5197531 A	30-03-1993	DE	4018924 A	19-12-1991
		AT	115020 T	15-12-1994

INTERNATIONAL SEARCH REPORT

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5197531 A		DE 59007941 D	19-01-1995
		EP 0463229 A	02-01-1992
		JP 2063995 C	24-06-1996
		JP 5031570 A	09-02-1993
		JP 7096157 B	18-10-1995
US 3532155 A	06-10-1970	NONE	
GB 2309405 A	30-07-1997	DE 19602554 C	18-09-1997
		JP 9206918 A	12-08-1997
		US 5778961 A	14-07-1998
EP 631832 A	04-01-1995	NONE	
EP 749790 A	27-12-1996	DE 19539770 A	02-01-1997
		EA 960020 A	31-12-1996
		JP 9010919 A	14-01-1997